

## Palladium(II) and Platinum(IV) Chloride Adducts with Adenine\*

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Received May 24, 1984

A wide variety of palladium and platinum complexes with nucleic acid bases and derivatives have been reported [2–15]. Complexes of these elements are of significant interest because of their potential antitumor activity. Regarding  $\text{Pd}^{2+}$ , several complexes of the types  $\text{PdL}_2$ ,  $\text{Pd}(\text{LH})_2\text{Cl}_2$ ,  $\text{Pd}(\text{LH})_4\text{Cl}_2$ ,  $\text{Pd}(\text{LH})_2(\text{OH}_2)_2\text{Cl}_2$  and  $\text{K}[\text{PdLCl}_2]$  (LH = neutral nucleobase or nucleoside) have been studied [2–4]. Numerous mixed ligand  $\text{Pd}^{2+}$  complexes, in which one of the ligands is nucleobase or derivative, were also reported, e.g., complexes with an amino acid [5–7], ethylenediamine or diethylenetriamine [8] as the second ligand. An even larger number of  $\text{Pt}^{2+}$  or  $\text{Pt}^{4+}$  nucleobase complexes were studied, so that only a few examples will be cited here: these include adducts of adenine (adH; I) with  $\text{Pt}^{2+}$ -ammine com-



plexes, such as  $[\text{Pt}(\text{NH}_3)_2(\text{adH})](\text{NO}_3)_2$  and  $[\text{Cl}(\text{NH}_3)_2\text{Pt}(\text{adH})_2\text{Pt}(\text{NH}_3)_2\text{Cl}]\text{Cl}_2$  [9, 10],  $[\text{Pt}(\text{NH}_3)_2(\text{LH})]\text{Cl}_2$  (LH = 9-methylxanthine) [11] (bonding of adH through N(6), N(7) [10] and 9-methylxanthine through O(6), N(7) [11] seems to occur in the preceding complexes),  $\text{Pt}(\text{adH})(\text{OH}_2)\text{Cl}_2 \cdot \text{H}_2\text{O}$ ,  $\text{Pt}(\text{adH}_2)\text{Cl}_3 \cdot 3\text{H}_2\text{O}$ ,  $\text{Pt}(\text{adH}_2)\text{Cl}_5$ ,  $[\text{Pt}(\text{adH}_3)\text{Cl}_3]\text{Cl} \cdot 5\text{H}_2\text{O}$ ,  $[\text{Pt}_2(\text{ad})(\text{OH}_2)\text{Cl}_7] \cdot \text{H}_2\text{O}$  [12],  $(\text{CH}_3)_3\text{PtL}(\text{tp})$  (L = 5,5'-dimethyl-2,2'-bipyridyl; tpH = theophylline) [13],  $[\text{tpH}_2][\text{PtCl}_4]$  [14], as well as complexes with mixed nucleobase-amino acid ligands [15]. The great majority of the preceding complexes were prepared from aqueous solutions. On the other

hand, these laboratories have developed a general method for the preparation of metal complexes of adH and other nucleobases (purine, guanine, xanthine, etc.) from non-aqueous media, by refluxing mixtures of ligand and metal salt in ethanol-triethyl orthoformate (teof) [16–20]. It was of interest to us to isolate and characterize the complexes formed by interaction of adH with palladium, platinum and other precious metal chlorides, under the conditions of our synthetic method [1]. Accordingly, work in this direction was initiated, and the present letter deals with adH adducts with  $\text{PdCl}_2$  and  $\text{PtCl}_4$ .

The new complexes were prepared as follows. The metal chloride (0.8 mmol) was treated for 2 h with a mixture of 35 ml ethanol and 15 ml teof at 50–60 °C, under stirring. Then, adH (1.6 mmol) was added and the resulting mixture was refluxed for five days. Following the refluxive step, the supernatant was reduced to about one-half its original volume by heating, and the solid complexes formed were separated by filtration, washed with ethanol-teof and stored *in vacuo* over anhydrous  $\text{CaCl}_2$ . Under these conditions,  $\text{PdCl}_2$  and  $\text{PtCl}_4$  yielded chocolate brown adducts of the  $\text{Pd}(\text{adH})\text{Cl}_2$  and  $\text{Pt}(\text{adH})_2\text{Cl}_4$  types. It should be noted that analogous synthetic work was performed with  $\text{PtCl}_2$ ,  $\text{AuCl}_3$ ,  $\text{RhCl}_3$  and  $\text{RuCl}_3$ . In the case of  $\text{M} = \text{Au}^{3+}$  or  $\text{Rh}^{3+}$ , well-defined complexes were obtained and are currently being characterized, but for  $\text{M} = \text{Pt}^{2+}$  or  $\text{Ru}^{3+}$ , the solids formed did not correspond to any reasonable stoichiometric formula (analytical data).

The new  $\text{Pd}^{2+}$  and  $\text{Pt}^{4+}$  complexes are insoluble in all common organic solvents. It appears that our synthetic procedure from non-aqueous media generally favors the formation of polymeric species [16–20], and as a result of this the new complexes involve lower adH to metal ratios, relatively to previously reported complexes. Thus, whereas most of the  $\text{Pd}^{2+}$  complexes with nucleobases and derivatives mentioned above involve 2:1 to 4:1 ligand to  $\text{Pd}^{2+}$  ratios [2–4],  $\text{Pd}(\text{adH})\text{Cl}_2$  is a 1:1 adduct. Likewise,  $\text{Pt}(\text{adH})_2\text{Cl}_4$  involves a 2:1 adH to  $\text{Pt}^{4+}$  ratio, whilst in the past a 3:1 analog was isolated from aqueous medium [12].

Both new complexes are diamagnetic, as would be expected for  $4d^8$  or  $5d^6$  species. Solid-state (Nujol mull) electronic spectra are as follows, nm: adH: 185vvs, 208vvs, 260vs,vvb;  $\text{Pd}(\text{adH})\text{Cl}_2$ : 198vvs,sh, 237vs,sh, 243vs, 258vs, 285s,sh, 307s,sh, 318s, 350ms,b, 405m,b, 497w,b, 536w,b;  $\text{Pt}(\text{adH})_2\text{Cl}_4$ : 183vvs,sh, 194vvs,sh, 238vvs, 245vs, 264vs, 281vs, 302s,b, 324ms,b, 353m,b, 396m,b, 437mw,b, 518w,b. The  $\pi \rightarrow \pi^*$  transitions of adH [21] undergo shifts and excessive splittings in the spectra of the new complexes, as indicated by multiple maxima at 183–285 nm. The  $n \rightarrow \pi^*$  transition, which is masked in the

\*Ref. 1.

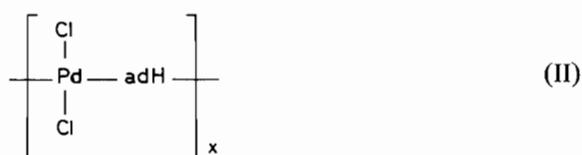
TABLE I. Pertinent Infrared Spectral Data for adH, Pd(adH)Cl<sub>2</sub> and Pt(adH)<sub>2</sub>Cl<sub>4</sub> (cm<sup>-1</sup>).

adH	Pd(adH)Cl <sub>2</sub>	Pt(adH) <sub>2</sub> Cl <sub>4</sub>	Band assignment <sup>a</sup>
2690w, 2600w	2900s, 2790s, 2700s, 2595s	2900s, 2800s,b, 2690s, 2605s,b	$\nu_{\text{NH}}$
1675vs	1668vs	1665vs,sh	$\delta_{\text{NH}_2}$
1600vvs,b	1612vs, 1598vs	1637vs, 1591vs	A' pym 8a
1565m,sh	1570s	1563s	A' pym 8b
1510w	1471mw	1482m	A' im R <sub>1</sub>
1419ms	1416s, 1390m,sh	1408m,b	A' im R <sub>3</sub>
1390w, 1370m	1390m,sh, 1366m	1387m,sh, 1368mw	A' pym 19a
1252s	1250s	1249m	$\delta_{\text{NH}_2}$ or $\delta_{\text{N}(9)\text{-H}}$ + ring mode <sup>b</sup>
1025m	1021m	1023m	$\rho_{\text{NH}_2}$ or $\delta_{\text{NH}}$
	361m	352m, 316m, 300m	$\nu_{\text{M-Cl}}$
	309m	278w, 266w	$\nu_{\text{M-N}}$

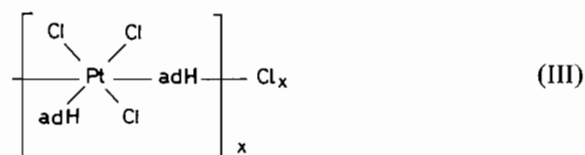
<sup>a</sup>Band assignments for free adH were based on refs. 22–26; pym = pyrimidine, im = imidazole fragment of the ligand. <sup>b</sup>Regarding the adH bands at 1252 and 1025 cm<sup>-1</sup>, ref. 26 characterizes them as  $\delta_{\text{N}(9)\text{-H}}$  + ring mode and  $\rho_{\text{NH}_2}$ , respectively, while in refs. 23–25 the band at 1252 cm<sup>-1</sup> is attributed to a  $\delta_{\text{NH}_2}$  asym out-of-plane deformation or to the  $\nu_{\text{C-NH}_2}$  mode, and the band at 1025 cm<sup>-1</sup> was either characterized as  $\delta_{\text{NH}}$  or remained unassigned. Note: The spectra of the complexes are devoid of  $\nu_{\text{OH}}$  absorptions, so that it can be concluded that no water or ethanol are present in these compounds.

spectrum of free adH [21], is detected at 302–307 nm in the spectra of the two complexes. Finally, the dark colors of the complexes are obviously due to strong charge-transfer absorption, originating in the UV and trailing off well into the visible region.

IR spectral data are given in Table I. Regarding the IR spectrum of free adH, band assignments were based on reported IR studies of purine (puH) [22] and adH [23–26] free bases and their metal complexes. As mentioned in footnote b of Table I, there is disagreement in the literature as far as contribution of NH<sub>2</sub> modes to the adH bands at 1252 and 1025 cm<sup>-1</sup> [23–26] is concerned. It is, nevertheless, clear from our data that all free ligand bands with potential NH<sub>2</sub> contribution (*i.e.*, bands at 1675, 1252 and 1025 cm<sup>-1</sup>) undergo significantly smaller shifts to lower wavenumbers, upon Pd<sup>2+</sup> or Pt<sup>4+</sup> adduct formation, than the shifts observed in the spectra of metal complexes containing adenine coordinated through the nitrogen atom of the exocyclic NH<sub>2</sub> group [16, 23–26]. On the other hand, various IR absorptions of free adH, corresponding to vibrational modes of the imidazole and pyrimidine rings of the ligand, undergo more sizeable shifts and occasional splittings in the spectra of the new complexes; this is consistent with exclusive coordination of adH through ring nitrogens in these complexes [16–20, 22–26]. It is also worth noticing that the new complexes exhibit  $\nu_{\text{NH}}$  bands, since they are adducts of neutral adH [22–26]. Tentative  $\nu_{\text{M-Ligand}}$  band assignments: the Pd<sup>2+</sup> complex shows the  $\nu_{\text{Pd-Cl}}$  mode at 361 and the  $\nu_{\text{Pd-N}}$  vibration at 309 cm<sup>-1</sup>. These features are compatible with a *trans*-square planar configuration for this compound [27, 28],



which would be anyway anticipated if a linear chain-like polymeric structure (II) with single adH bridges between adjacent Pd<sup>2+</sup> ions [16–20] is assumed (*i.e.*, *trans*-PdN<sub>2</sub>Cl<sub>2</sub> moieties). In the case of the Pt<sup>4+</sup> complex, three  $\nu_{\text{Pt-Cl}}$  and two  $\nu_{\text{Pt-N}}$  bands were identified [29]. This polymeric complex must involve a *trans*-PtN<sub>3</sub>Cl<sub>3</sub> cationic species, which is compatible with the IR evidence [30], and an ionic Cl<sup>-</sup> group per Pt<sup>4+</sup> ion. Structural type III, which again involves single adH bridges between adjacent Pt<sup>4+</sup> ions, as well as a terminal adH ligand on each metal ion, is applicable in this case.



The polymeric structures II and III are supported by the insolubility of the new complexes in organic media and the pronounced tendency of adH to function as a bridging ligand [16, 31]. Bridging through chloro ligands can be ruled out, as no IR

bands attributable to  $\nu_{M-Cl}$  (bridging) modes were found in the spectra of the complexes. As regards the likely binding sites of adH, the terminal ligand in the  $Pt^{4+}$  complex would be certainly coordinated through the N(9) imidazole nitrogen [16, 31–34]. N(9) would be also one of the binding sites of bidentate bridging adH, while the second binding site might be either the N(7) imidazole or the N(3) pyrimidine nitrogen. Both the N(3), N(9) [35–37] and N(7), N(9) [38, 39] combinations have been established for  $Cu^{2+}$  or methylmercury(II) complexes with bidentate bridging adenine or purine, while in the case of a  $CH_3Hg^+$  complex with tridentate bridging adenine coordination occurs through N(3), N(7) and N(9) [40]. In view of the postulated presence of single adH bridges between adjacent metal ions in structures **II** and **III**, it is considered as more likely that N(7) and N(9) are the actual binding sites of bridging adH in the new complexes. In fact,  $[Cu(puH)(OH)_2]_4SO_4 \cdot 2H_2O$ , which is a linear chainlike polymeric species with single puH bridges, contains N(7), N(9)-bonded bidentate purine ligands [38].

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